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Experimental Test Pilot

A380: Development of the Flight Controls

Part 2

The Lateral Flight Control Laws

On July 27th 2005, in Toulouse we had a strong wind from the south, called "vent d'Autan", giving rise to a lot of turbulence. It was flight 51 of the first A380. We performed several landings and it became apparent that the lateral flight control laws would have to be tuned again: the pilots were very active on the stick, the ailerons were moving a lot and created unpleasant lateral accelerations, mainly at the back of the aircraft. The flight test engineers had several possibilities to adjust the control laws: gains, damping…, but none of them could solve the issue. This typical development flaw had to be corrected, but it was not an easy task.

Mid October, new PRIM flight controls computers were delivered with a new control law for the ailerons that the engineers of the design office called "VDA" or "Valse Des Ailerons" (ailerons waltz). As an example, when moving the stick to the left, on the left wing, the internal aileron started to move up immediately. The outer aileron was doing the same, but with a different deflection. Finally, the centre aileron was either initially going down, in opposition to the two others, then taking an upward position, or going up after a very short delay in a neutral position. Several adjustments were available for the flight engineers, for example, the ratio between the deflection of inner and outer ailerons and the logic of the centre aileron. The target of this strange kinematic was to "break" some wing oscillations as two of them had very close frequencies and, in certain circumstances, they had the possibility to couple together. Looking at the page dedicated to the flight controls on the screen at the disposal of the crew, it was easy to understand why this strange motion of the ailerons received this nickname of "VDA". A similar differential deflection was also implemented on the two rudders and was called "VDR" or "Valse Des Rudders" (rudders waltz), a typical Airbus "British – French" acronym, as rudder is not a French word! The improvement on comfort was spectacular. However, some tuning was still needed.

In January 2006, we installed a new standard of the computers, with some improvements on the VDA laws. The main one was a reduction in the activity of the ailerons. The adjustments were again performed in flight. The final tuning is such that, for speeds below 300 kts, the deflection of the inner aileron is 2.5 times the value of the outer one. The centre aileron follows the inner, but with a time delay of 350 milliseconds. Some more modifications were needed at high altitude due to the Mach effect.

But we had another issue: the tuning of the spoilers. At the beginning, they were deflected as soon as there was a command in roll and this created some buffet. Mid February 2006, new settings were proposed by the design office in order to reduce these vibrations, with a limitation of the deflection to 3° as long as there was not a strong demand from the pilot. Without this trick, one of our British test pilots told us that he had the impression of being "punished" by this buffet when entering a standard turn! On top, in the final tuning, when more manoeuvrability was needed, there was a higher deflection of the outer spoilers than of the inner ones, because they were creating less buffet.

For all these flights where it was important to get an idea on the comfort, a qualitative judgement at various locations in the plane was needed. In the cockpit, the pilots gave their impressions, both on the ease of flying and on the comfort in the forward part of the aircraft. The flight test engineers, seating close to the centre of gravity, gave their sensations based on their

feelings and the available traces. At the back, close to the most rear door of the main deck, we installed a seat equipped with an intercom connected to the other crew members. A young flight test engineer was sat there, to give his opinion about his perception of comfort. Taking into account the number of roll manoeuvres we were performing on each flight, we had to hope that he would not become sick! It is true that a choice could have been made based on an analysis of the traces of several parameters of the motion at the various positions in the plane, but we considered that the opinion of a potential "passenger" was fundamental in order to make the final decision. Obviously, all the records of these parameters were used by the design office to make progress in the tuning of the flight controls laws. It is to be noted that, at the beginning of the program, we were concerned by a possible difference of comfort between the two decks. The first flights demonstrated that this was not an issue.

At the opportunity of your next flight on an A380, if you travel in business or economy class, I recommend that you book a "window seat", close to the wing or at the back of the plane in order to see how the ailerons are working (in first class you will not have this chance as you will be too far forward!). The effect is best observed just after take-off and during the early climb manoeuvres with the ailerons moving around their neutral position. You will see that when entering into a simple turn or for a unique roll correction, taking as a base the inner aileron, the one closest to you, the outer aileron will move simultaneously but with a smaller deflection. Then with a small time delay, the centre will join the inner. If several corrections are made by the pilot, in one direction then in another, taking into account the different deflections and the time delay, you will see the ailerons in totally different positions, up and down. The nickname "Valse Des Ailerons" is really well chosen and it is efficient.

The High Angle of Attack Protections at Low Mach Number

The tuning of the high angle protections, that prevent loss of control for all types of manoeuvres at low speed, has to be performed on all our new aircraft. The flight test techniques are well known by the test pilots.

We start with some decelerations with the engines at idle, slow manoeuvres at first and then faster, until achieving full back stick. At this stage, we have to check that we have some margin before reaching the stall. These tests are repeated in a stabilized turn and also with full thrust. If all the results are satisfactory, some rapid roll manoeuvres are carried out in one direction then in the other, while maintaining full back stick with various thrusts between idle and take-off power. The conclusion is the "avoidance manoeuvre" where the pilot rapidly puts the stick in the aft corner: a very rapid turn will commence, the angle of attack will reach its maximum, and the engines will go to full thrust. This is exactly what a pilot would do to avoid another airplane or an obstacle. These tests must be performed for all slats and flaps positions. They must also be carried out for the extreme positions of the centre of gravity and with an aircraft light or heavy, as the reaction will be a function of all these parameters.

During the first flights of the A380, we performed an evaluation of these protections, but in a quasi-static way, with a slow deceleration. The reason was that we had to avoid approaching the stall because of potential high loads on the empennage. The engines were at idle and the target was to get a first idea of the tuning. During flight 7, at aft CG, we carried out some of these decelerations with satisfactory results.

The real tuning started when the slats and flaps deflections were frozen, end of July 2005, and immediately, we had a flight dedicated to these adjustments. We performed the tests at mid and aft CG, as the CG position could be adjusted in flight thanks to the water ballast system and when necessary some fuel transfer. During this flight, we avoided manoeuvres that were too dynamic, as we had still some doubts concerning the loads on some parts of the aircraft. The results were globally good, with the exception of the configurations 3 and Full, where the angle of attack was not properly stabilised when at full back stick, with therefore a risk of reaching the stall. So, for these configurations, we initially decided not to perform the turns with full back stick and maximum thrust.

The tuning continued with various standards of the PRIMs and, very quickly, in October 2005, the tuning of the protections was satisfactory. We proved that

at the Dubai Airshow where we performed the standard flight display, with high angle of attack manoeuvres, similar to the display carried out on all other Airbus types.

The Effect of Icing on the Tuning of Low Speed Protections

However, the tuning of the protections at low speed was not complete. We had to ensure that with some ice on the leading edge of the wing, the protection is still doing its job properly. This is not a critical issue on big transport jets, as due to their rather high speed, it is far more difficult to accumulate a large amount of ice on the wing than on smaller and slower aircraft. But the certification regulations are the same for everybody, and obviously we had to comply.

Some tests are performed in real icing conditions, but it is not possible to accumulate on the leading edge an amount of ice giving a shape representative of the "worst case" required by the regulations. Therefore, the aerodynamicists compute for all flight phases, the ice shapes for the wings and the empennages for the most critical conditions. In order to avoid performing several series of tests with different shapes, only the most critical for all flight conditions is retained.

The ice shapes are then manufactured. They are made of polystyrene with some additional particles glued on in order to simulate the granularity of the ice. These shapes have a thickness of three inches, which is considered to be the maximum that an aircraft will keep on a leading edge. The regulations also consider that the de-icing system may fail. In this failure case, the relevant part of the wing is equipped with a smaller ice shape, as the crew will follow the procedures to leave the icing area, and therefore will accumulate a smaller amount of ice. These ice shapes are then glued on the leading edge for the duration of the tests.

Figure 1
Polystyrene shapes simulating ice accretion

With the shapes in place, the tests start with an evaluation of the handling qualities and some stalls in order to check if the margin between the stall and the approach speed remains acceptable or not. If it appears that this margin has become insufficient, it is possible to recommend a small approach speed increase, such as 5 kts in case of severe icing or failure of the de-icing system. On the A380, none of the speeds or procedures needed to be changed in icing conditions.

The second step is to review the high angle of attack protections and adjust them, if necessary. The test techniques are identical to those used without ice shapes.

On the A380, on each wing, the slats are divided in seven sections and only slat 4, close to the outer engine, on the fuselage side, is de-iced. Within the flight test team, we were convinced that this de-icing was not necessary. What could be the effect of a couple of inches of ice on such a huge leading edge? This design change could save around sixty kilograms of weight (about half a passenger!). Therefore we decided to start the tests with a configuration without the de-icing, which means with the three inches leading edge ice shapes on all the wings, including slats 4.

The first flight with ice shapes was performed on June 26th 2006. As mentioned above, we started with the stalls. With flaps retracted, the results were good. But there was a significant deterioration as the flaps were deflected. For the landing configuration, there was some loss of lift and a pitch up when approaching the stall. Our objective was to keep a safe aircraft, without degradation of the performance. Retaining more or less the same tuning for the angle of attack protections would have been an acceptable solution to save weight and simplify the systems. But, due to the pitch up, it appeared that the maximum angle of attack with the protections, in the landing configuration, would have to be reduced by two degrees, which was really too much. And therefore, we had to keep the de-icing system on slat 4. The flight test team was wrong and the aerodynamicists were right!

The tests continued with the tuning of angle of attack protections. The maximum angle of attack remained unchanged from configuration Clean to 2. Then in configurations 3 and landing, there was a reduction of 0.5 degree, without any consequence on the operation of the aircraft.

The tests were concluded with the validation of the failure case, a small ice shape on slat 4, with no other modification. Considering the previous tests with this slat fully iced, we were anticipating some degradation of the handling qualities. All we found was a slight difficulty to maintain the bank angle precisely with full back stick in the landing configuration. This was found acceptable due to the fact

that this is a situation that will most probably never be found in the life of all A380s: the most severe icing conditions, associated with a failure case and a pilot maintaining the maximum angle of attack during several seconds. And anyway, it is perfectly safe as control is not lost.

In summary, these ice shape tests led only to a very small reduction of the maximum angle of attack in the flight controls protections in configurations 3 and Full.

The High Angle of Attack Protections at High Altitude

The aircraft must also be protected against the loss of control during decelerations and in turns at high and medium altitude with slats and flaps retracted. In these conditions, when the pilot pulls on the stick, without flight controls protections, the classic stall characteristics are not easy to detect as there is no visible stall nose drop compared to low altitude with the flaps extended. On the other hand, the buffeting appears progressively and, if the pilot insists and continues in the manoeuvre, eventually reaches a deterrent level. The angle of attack to get the deterrent level of buffet reduces with the Mach Number and therefore the tuning of the protections has to be done for all Mach Numbers.

For these tests, for each Mach Number, the crew chooses an altitude where he can perform tight turns, without imposing an excessive load factor. An exploration is performed without protection, in direct law, in order to identify the angle of attack of the appearance of the buffeting and of the deterrent buffet. These manoeuvres are difficult to perform, even for well trained test pilots, because, for the measurements, the Mach must be maintained precisely. It is controlled using the bank angle: as an example, decreasing the bank angle in case of Mach increase (more nose up to decrease the rate of speed acceleration). Then, using these results, a first tuning of the protections is performed immediately and tested, the target is to be at the limiting level of the buffet when full back stick is reached. The tests start with turns where the load factor is very slowly increased. Then turns with fast increase of load factor are carried out. If, with the initial tuning, the buffeting is not found, the engineers will increase the maximum angle of attack by half a degree and re-perform the tests. On the other hand, if there is too much buffeting during all the manoeuvres, the maximum angle of attack must be reduced. As there is some scatter in the results of the manoeuvres, the ideal situation is to be just at the limit of the buffet. This implies having, sometimes no buffeting during smooth manoeuvres but reaching very briefly a strong buffet for aggressive pitch entries.

In summary, for each Mach Number, the tuning is carried out by progressive adjustment. It has to be repeated at various Mach Numbers in order to obtain the curve of maximum angle of attack versus Mach Number. These tests are first performed at forward CG. They must then be repeated at aft CG, which is usually done during the same flight. At aft CG, depending on the characteristics of the flight controls, it may be necessary to reduce very slightly the maximum angle of attack. If everything goes well, at the end of the flight, all the tunings are decided and will be transferred in the next standard of flight controls computers.

On the A380, we started these tests on August 31st 2005. It was flight 78 of aircraft MSN 1. The results were not fully satisfactory for several reasons. The development computers did not allow us the possibility to insert the right tuning for Mach between 0.6 and 0.7. We also had difficulties in flying the aircraft in roll between Mach 0.80 and 0.84 and therefore, measurements were not very good. Finally, between Mach 0.80 and 0.89, the aircraft exhibited some pitch up (which means that it had a tendency to pitch up without pilot input) and was entering buffet very quickly.

These various problems were progressively solved. It is to be noted that the pitch up pheno-menon lead to a very delicate adjustment of the flight controls. When it appears, the flight controls law has to deflect the elevator down smoothly to oppose this immediate and strong motion pitch up effect. Finally, on May 10th 2006, a final revue of the adjustments was performed with very good results.

However, some more flights were needed to validate the behaviour of the protections with the airbrakes out. The issue was that the pitch up, if the pilot insists and continues in the manoeuvre, is a function of the deflection of the spoilers and as their extension is destroying the lift, it also reduces the pitch up. Therefore the “anti pitch up” function of the flight controls laws is adjusted according to the airbrakes position. On the A380, the first tests with airbrakes out demonstrated that the estimations obtained by models and wind tunnel were not correct. To cope with this situation, we performed some identification flights in direct law, with various airbrakes deflections, in order to define the automatic compensation to be introduced in the computers.

Part 3 will include the development of the high speeds protections, the BUSS (Back Up Speed Scale) and the BCM (Back Up Control Module).

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A400M
Formation of five A400M nose to tail at Toulouse-Blagnac Airport

Safety First, #14 June 2012. Safety First is published by Airbus S.A.S. - 1, rond point Maurice Bellonte - 31707 Blagnac Cedex/France. Editor: Yannick Malinge, Chief Product Safety Officer, Nils Fayaud, Director Product Safety Information. Concept Design by Airbus Multi Media Support Ref. 20121045. Computer Graphic by Quat'coul, Fixion, Abac Effect. Copyright: GS 420.0029 Issue 14. Photos copyright Airbus. Photos by Pascal Chenu, ExM Company: P. Masclet. Printed in France by Airbus Print Centre.